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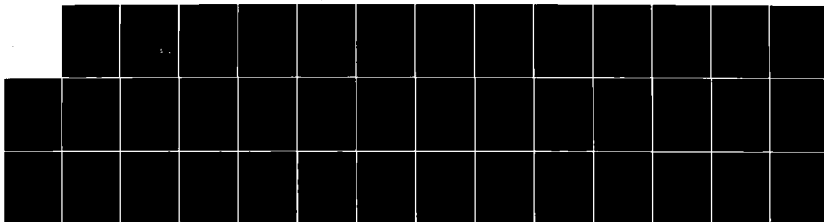
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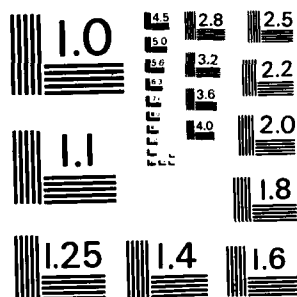
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FINAL REPORT *

SYSTEMS DESIGN PROCEDURES FOR IMPROVED EFFECTIVENESS
OF MILITARY SEA TRANSPORTATION SERVICE OPERATIONS

July 31, 1983

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Executive Summary

This research was sponsored by the Office of Naval Research and was directed at understanding and improving systems design procedures in support of Department of Defense surface transportation and traffic management. The primary focal point of the research was Military Sealift Command (MSC) operations and their interfaces with the Military Traffic Management Command (MTMC).

In Section 1 we discuss the objectives and scope of this research. In Section 2, we describe surface transportation activities and supporting management systems through a horizontal view (the logistics supply chain and its associated agencies) and a vertical view (the strategic, tactical, and operational decision processes for planning and control); In Section 3, we consider the operational level in more detail and describe basic processes and systems associated with cargo traffic management. This provides a perspective on the problems of horizontal data and system integration across the several agencies and processes supporting cargo traffic management. and In Section 4, we discuss design and implementation issues. The key issue is the degree of (de)centralization of control/responsibility for design, development, and data specification within and among agencies in the transportation and deployment community. Finally, In Section 5, we summarize several pressing problems with the current state of

defense transportation systems and delineate research opportunities which we view as promising.

Briefly, our major conclusions concerning current transportation ADP and system applications are:

1. There is an alarmingly low level of actual implementation of information systems, especially at MSC, in spite of the existence of competent macro system designs for many operational systems.
2. The horizontal and vertical interfaces between organizations and within planning processes is poor, leading to time-consuming, error-prone human intervention and poor responsiveness in both planning and execution of several key activities, including strategic mobilization planning.
3. A decision orientation to provide guidance for system design activities is not apparent in the current system. This results in part from uncertainties resulting from the current debate on merger of MSC and MTMC.
4. There is a lack of focus in current systems on defining the scope of (de)centralization of design, development and implementation of transportation systems. The present technology is oriented towards transactions processing, not (model-based) decision and command support.

Based on these conclusions, we recommend future research and development in three areas: system design, performance evaluation, and model development.

System Design: An immediate priority should be to move ahead with the design and implementation of operating systems at MSC. Such operating systems in support of traffic management will be needed in any case to provide a foundation for communication and data systems for the evolving Joint Deployment System.

Performance Evaluation: A major effort should be undertaken to define operational performance measures and associated management control systems to determine how well the defense logistics system is capable of fulfilling its strategic missions. Such systems would be designed to track and diagnose effectiveness (e.g., response-time) and efficiency (e.g., resource) problems in traffic management.

Model Development: A final area recommended for near-term research is model-based support of Joint Operations Planning. Here we suggest investigating the potential use of recent research results on industrial job shops to improve the present unwieldy (and probably unreliable) approach to Joint Operations Planning. What is needed is a planning approach that recognizes that the specific scenarios (and data) used in mobilization planning will never materialize in practice because of environmental contingencies and uncertainties. Thus, more flexible and responsive planning systems are required than those that appear to be either available or planned for the support of Joint Deployment Activities.



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1. Introduction

This research was sponsored by the Office of Naval Research and was directed at understanding and improving systems design procedures in support of DoD surface transportation and traffic management. The objective of this study was to investigate the use and potential impact of state-of-the-art information systems technology and model-based planning procedures in support of decision making for defense surface transportation. The research investigators were initially concerned only with Military Sealift Command (MSC) operations and its interfaces with the Military Traffic Management Command (MTMC), but we quickly learned that defense transportation and traffic management are inseparable from broader issues of joint deployment and strategic mobility planning. Our study has therefore also considered these more strategic issues as they relate to surface transportation and traffic management.

Our research specifically excluded any consideration of the merits of proposals to merge MSC and MTMC into a unified command structure. This question has been studied in a separate research project [Keech, 1983]. However, two issues related to the merger question are discussed in this report. First, we discuss guidelines for determining which system design and development activities should be (de)centralized to operating and area commanders and which require more centralized coordination and

planning. Second, we discuss the interaction between the definition of organizational boundaries among TOA's and the choice of information technology for decision support in these agencies. In particular, at the operational level of traffic management, we find that the definition of organizational boundaries is less important than the definition of compatible data transfer and control procedures.

This study was quite limited in scope and was directed at providing conceptual foundations for follow-on research and design activities. The procedure followed was to interview knowledgeable parties at MSC, MTMC, JCS, and the Department of the Navy. On the basis of these interviews and extensive documentation provided by our respondents (see references for a partial listing of source materials), we formulated a macro descriptive model of surface transportation activities and associated planning and management systems. This led to the development of a decision-oriented approach to macro design and to the identification of research opportunities for more effectively supporting decision making in surface transportation and traffic management. The results of this study are summarized briefly below.

In Section 2, we describe surface transportation activities and supporting management systems through a horizontal view (the logistics supply chain and its associated agencies) and a vertical view (the strategic, tactical, and operational decision processes for planning and control). In Section 3, we consider the operational level in more detail and describe basic processes and

systems associated with cargo traffic management. This provides a perspective on the problems of horizontal data and system integration across the several agencies and processes supporting cargo traffic management. In Section 4, we discuss design and implementation issues; the key issue is the degree of (de)centralization of control/responsibility for design, development, and data specification within and among agencies in the transportation and deployment community. In Section 5, we summarize several pressing problems with the current state of defense transportation systems and delineate research opportunities which we view as promising.

2. A Macro Model of Defense Transportation

The focus of this research is the design of decision-oriented systems for defense transportation. The starting point for this analysis is a descriptive model of defense transportation. The model presented here is based on one developed by the Office of the Chief of Naval Operations, Logistics Plan Division (OP-40), as elaborated by RAdm Richard Avritt and his staff. This model is oriented toward understanding three interacting elements:

Decisions: What are the key decisions involved in transporting cargo, passengers, and POL in support of defense organizations under various scenarios (specific to war, peace, and theatre of operations)?

Organizations: Which organizations and command centers are responsible for making decisions and for designing and maintaining systems in support of these decisions?

Systems: What data, models, processing routines, and information technology will be used to implement specific decision-support functions?

Figure 1 presents an aggregate picture of these three interacting elements. The driving element is the set of decisions and scenarios underlying the defense transportation system. In the simplest terms, this is the defense transportation mission statement: effectively fulfilling logistics requirements for planning and execution of supply and resupply requests under various pre-planned scenarios and operational conditions. The decisions and planning and control processes associated with this mission may be viewed at several different levels. At the strategic level, capacity (e.g., size, control, and composition of rail and shipping fleets), readiness, and responsiveness characteristics of the system are chosen and evaluated and overall control is exercised. At the tactical level, resources (such as ships, personnel, and terminal facilities) are positioned and managed. At the operational level, demands for shipments are entered and serviced.

The second and third elements depicted in Figure 1 are the nature of goods transported (cargo, POL, and passengers) and the organizations involved operationally in generating demands on the

defense transportation system and in fulfilling these. A more detailed view of these two interacting elements is presented in Figure 2. There we show the end users, the CINCs and the Joint Chiefs of Staff (JCS), initiating preplanned and spot requests for transportation services, which are processed and encoded for execution by the supply organizations (depots, vendors, force deployment commands) and mode operators (MAC, MSC, and MTMC). These transportation requests are then carried out through joint activities by the supply organizations and mode operators, and their progress and successful completion is monitored.

Several different perspectives are useful in viewing decision support activities in this environment. At the most basic level, the traffic management function must be supported in providing for the movement of goods and personnel and associated transactions processing within the logistics chain of supply-mode operator-end user. A second perspective is the command level (strategic, tactical, and operational) associated with planning and control of the transportation system. The third perspective in systems design is the definition of organizational boundaries for agencies and commands responsible for various activities in the system.

These three perspectives can generate a large number of alternative system designs, depending on the manner in which they are mutually defined and coordinated. A concrete recommendation on the proper integrated perspective for systems design and control would require a much more detailed study than our limited research project allowed. A first step in this regard is to

understand the different nature of activities and responsible organizations involved in defense transportation. The following classification of these activities and supporting systems is useful for this purpose.

Corporate: Personnel, financial, and administrative systems serving the parent services involved (Army, Navy, MARAD, etc.).

Transportation: Systems (e.g., JOPS, SEACOP, CALSTAT) in support of strategic, tactical and operational planning and control of the overall transportation system per se, including booking, routing and scheduling systems.

Mode: Systems specific to the operational control of alternative transportation modes/handling facilities (e.g., SMIS, Rail and Ship Loading Systems, Terminal Management Systems).

A summary of the interactions between the above three types of systems and the decision processes they support is presented in Figure 3, where we depict the interaction between command levels, organizational responsibilities, and physical and data flows inherent in the present system. This Figure illustrates several key issues for systems design and implementation.

Decision-Oriented Systems: In the final analysis, information systems and models are implemented to support decision-making, execution and control. Thus, the fundamental issue in any systems design perspective is the delineation of the decision, planning, and physical processes of interest. This may

seem trite, but it is not. For example, is the purpose of JOPS and OPLANs to allow the JCS and JDA to decide and pre-plan the aggregate feasibility of force movement and resupply schedules under given scenarios (with detailed feasibility evaluation under the control of responsible TOAs)? Or is it to determine force movement and resupply schedules in detail? If the first (aggregate feasibility) view is maintained, then the set of information which would be made available to the JDA would be only that required for them to make aggregate capacity and force movement decisions. If the second (detailed) view is maintained, then much more detailed information would have to be accessible to the JDA to generate the desired output. The consequences for database management, communications, and systems support would be rather different for each of these views.

Communications and System Interfaces--Filters: The issue just raised points to the critical importance of designing communications and system interfaces with a view towards what information is needed to support decision processes at the proper level. Continuing our example of generating OPLANs, a major problem with the present process is in obtaining data in a format which is readily usable in lower level evaluation processes. For example, MSC needs its data on deployment and resupply schedules to be translated into a format compatible with ship loading (e.g., data indexed by source, destination, volume, weight, cargo classification, and special handling and shipping requirements). MTMC uses other transportation modes and must interpret OPLAN data

relative to these modes. The JDA is concerned with such transportation-specific data only to the extent that it affects timing and feasibility issues of force movements and resupply requirements. At present, large efforts, involving thousands of hours of manual and imperfect interventions, are involved in translating the requirements of one agency to those of another. Automating this process will require a delineation of compatible data formats and translation systems to support the processes specific to each agency/organization.

Local/Global Systems: The third issue of importance arising from Figure 3 is the distinction between local and global systems and data. One of the most important lessons we have learned in information and decision support systems over the past two decades is the difficulty of designing, implementing and maintaining large, complex centralized systems. Efforts to design totally integrated data bases and systems for large endeavors have had a very low success rate and are a thing of the past. The present philosophy favors distributed data acquisition, maintenance and processing. This permits an evolutionary approach to designing and implementing smaller pieces of the overall system. It also presents us with a set of major design choices: which decisions and planning processes will be under the local control of specific agencies and which will be designed to encompass several agencies.

Locally controlled systems may, of course, involve some design standardization and joint prototype development to avoid duplication of effort. In the case of global or inter-agency

systems, considerably larger amount of resources must be devoted to the initial and on-going coordination problems of making systems used and useful to all agencies involved. In the absence of such coordination, systems will tend to fragment to fit only local user needs. The on-going debate about MSC and MTMC planning procedures is a good case in point. Each currently treats the other as a "black box" in its own planning processes for cargo movement and handling. Efforts to totally integrate their joint system development activities would be very complicated to implement (given the diverse nature of the transportation modes each is responsible for). Yet some joint planning and control systems and databases must be established to improve the efficiency and effectiveness of their overall function. (The same local/global tradeoffs exist in coordinating the development of systems employed by area commanders within each TOA.) Delineating which systems will be jointly planned and maintained, and which locally, is the key issue here.

Using the above systems/activities classification (corporate, transportation, mode), one would expect as a general guideline that corporate systems would be designed and maintained by parent services, mode systems would be local to mode operators, and transportation systems would be centrally (i.e., globally) designed (though very likely implemented and maintained locally). There are many interactions between these system types, however, so more detailed analysis is clearly necessary.

In order to explore the above issues in a more concrete fashion, we now consider the operational level of planning and systems development (the cargo traffic management function) in more detail.

3. Issues in Systems Design for Cargo Traffic Management

In this section we examine the operational level of cargo traffic management in order to illustrate the interaction between management activities and information system elements in developing a management support system. It is possible to view the system from at least three different perspectives: physical flows, information flows, and organizational responsibilities. It is difficult to capture all of these perspectives at once, so a good starting place is to consider the physical reality -- namely, the flow of goods. Figure 4 shows this process for containerized cargo moved from CONUS to Europe. The top row of boxes depicts stages of movement for containerized cargo, and the bottom row indicates the flow of empty (or partially loaded) containers in the opposite direction since there are also significant management problems associated with containers. This figure would have to be modified slightly to accomodate other types of cargo -- e.g., breakbulk or POL -- mainly by eliminating the return path for containers.

The performance of this system is measured in terms of effectiveness and economy in carrying out its mission. Some specific criteria are:

Effectiveness:

- Meets requirements for throughput
- Meets due dates
- Accommodates priorities

Economy:

- Fees to carriers
- Utilization of resources -- e.g., number of ships, railcars, containers, personnel
- Inventory costs for cargo in the pipeline
- Sloppiness costs -- e.g., detention, overtime, excess warehousing
- Information processing -- e.g., paper handling, redundant data entry, status monitoring

In the chain of management systems employed by TOA's to connect the supplier of material and the end user, the activities of Booking, Routing, and Scheduling are generally viewed as the key processes. Figure 5 indicates a useful way of thinking about these processes in two ways. First, we have labelled as "Management Activities" four types of functions that must be accomplished in doing the job. At the bottom of the Figure, labelled "Information Systems Elements", are found types of information systems and data processing operations that may be used in support of these functions in building management systems. More specifically, we define the four management functions as follows:

1. Decisions are the choices to be made in allocating transportation resources to the tasks that must be accomplished, including determination of the when, where, and how of traffic movement. Explicit identification of these decisions is critical since system performance depends on supporting these decisions. The alternative focus on functions or processes leads to misdirection in system design and lower performance of the resulting system design.
2. Monitoring and control involves gathering status information and verifying that planned events take place. This closes the loop on the decision making steps to ensure that decisions are successfully implemented and that assumptions have not been violated.
3. Evaluation relates decisions to information gathered from monitoring and control activities in order to measure performance against the criteria mentioned above.
4. Documentation, requests, and notification are the vehicles for communicating information about decisions, anticipated events, and status.

Table 1 provides further examples from each of these categories.

In order to remain unconstrained in thinking about the management of cargo movement and the systems to support that function, we are purposely not elaborating on organizational responsibilities for specific decisions and tasks or the details of "paper handling".

Each of the typical decisions listed in Table 1 may be made sequentially and in isolation, and in practice, often is. However, these decisions actually interact; for example:

1. Booking and scheduling: the choice of a carrier is dependent on its schedule, but the schedule may be determined by the location and volume of cargo available.
2. Booking and routing: the choice of a carrier implies a date by which a container must reach a terminal and hence a choice of routes; choosing the route before the booking affects container utilization, the POD, and hence the choice of a carrier and POE.

Hence, a proper system perspective must recognize and accomodate these circular, interacting decision activities.

In order to illustrate the design problem, we will explore a scheduling problem in more detail. Consider the problem of scheduling a ship to call at a port. In developing a methodology for solving this problem, there are many options in terms of what data are to be considered and which other previously made decisions are to be taken as constraints, ignored, or possibly changed. For example, the system could (1) attempt to have a ship arrive at a given port once every week, regardless of the amount of available cargo; (2) alternatively, one could attempt to achieve better responsiveness and higher utilization by planning ship arrivals in accordance with projected levels of cargo availability; (3) a more ambitious system might attempt to simultaneously schedule the arrival of cargo and ships to the POE. Still ignoring traditional assignments of responsibility for decision making, definition of the scope of this particular scheduling problem involves tradeoffs along several dimensions:

1. The definition of meaningful, quantifiable tradeoffs among alternative performance measures.
2. Inclusion of detailed status information and forecasts.
3. Accomodation of uncertainties arising from unpredicted events.
4. The number of alternative solutions explored and hence the level of payoff achieved.

5. The cost of solving the defined problem relative to the expected benefits.

Referring back to the three scheduling approaches mentioned above, one might observe that Option 1 is taken by commercial carriers using aggregate data since their influence on demand is limited. The current defense logistics system seems to use an approach similar to Option 2 combined with an optimizing methodology. Option 3 represents an expansion of the scope of the problem, but using more highly aggregated data describing more of the world and heuristic (as opposed to mathematical optimization) techniques. Although it represents a more difficult problem than either Options 1 or 2 and may require the realignment of organizational boundaries, Option 3 has the potential for a higher payoff than either of the other options.

The information system elements in Figure 5 have the following interpretations:

1. Transaction processing involves capturing, entering, verifying, and storing data related to decisions and events.
2. Communication means transmitting information between users either on a routine basis or upon request.
3. Inquiry involves extracting, filtering, aggregating, and displaying information from the organizational database in support of the management activities.
4. Model usage is employing procedures to support and facilitate decision making once the necessary information has been assembled through inquiry processes.

The development of these information system elements is highly

dependent on the availability of suitable computer technology; there are also many alternative approaches to satisfying management's information processing requirements.

Ultimately, the determination of the scope of a particular problem, such as scheduling, implies a range of specific management activities and responsibilities -- e.g., types of decisions, monitoring activities -- and specific information access and processing requirements that must be supported by the various information system elements. We recognize that these processing requirements may be difficult or impossible to satisfy with current technology or within current organizational constraints. However, three observations can be made. First, this problem may be approached by iterating between the design processes for management activities and information system elements until the conflicts are resolved. The critical point is that this iteration must begin with the consideration of management activities rather than the available or planned information systems. Second, although this design process is a difficult one to follow, it provides the highest potential for developing a satisfactory system design. Third, even once an appropriate design is developed, the remaining task of building the system may still be a very difficult one. Section 4 discusses a number of issues and considerations in building such large and complex systems and suggests an approach that employs state-of-the-art technology to simplify this problem.

To the extent that the scope of a management activity expands to include multiple parts of the physical system, serious problems of system integration and horizontal information flow among organizations may arise. For example, if a particular decision requires a model of wide ranging scope, many information system elements are affected:

1. The inquiry component must accomodate more diverse requests involving a wider range of data.
2. The communication system must provide access to information from more organizations' databases.
3. The transaction processing systems must capture and store new varieties of data.

The resulting issues of compatibility and interface are difficult ones that must be addressed in both the systems design process and the way in which system design responsibilities are allocated among organizations.

4. ADP Activities in MSC: Observations, Concerns,
and Recommendations

The first and most obvious observation regarding ADP activities at MSC is that there are many systems involved, either in use (e.g., SEACOMIS, SEACOP) or planned (e.g., SEASTRAT, CMSS, SID). This situation implies potentially large manpower and resource commitments to the development and long-term maintenance of these systems, as well as a long lead time for implementation. For instance, SEACOMIS alone consists of hundreds of programs and

apparently still does not satisfy all the needs identified in the corresponding areas of the Command Information Flow Matrix developed using the Business Systems Planning methodology. While the number and complexity of such systems may be consistent with MSC's mission, a master Information System plan must directly address the potential problems with lead times and costs resulting from the use of conventional systems development methodologies.

Currently, systems are scattered over many processing sites (e.g., CNO WWMCCS H6060, MTMC's H6060, Navy Manpower Center, David Taylor R&D Center) and types of operating systems and hardware with only limited opportunity for automated interfacing, let alone integrated information access. Since MSC does not operate its own DP installation, it has only limited control over processing priorities, thereby making response times long and unpredictable and decreasing the perceived reliability and usefulness of computer-based systems. In particular, this type of processing environment is incompatible with the support of activities such as time sensitive execution planning in the event of a crisis.

Limited access to secure lines and reliance on low speed communication links suggest that timely communication could not be achieved in an emergency. Even in peacetime operation, these facilities foster a complete decentralization of processing and information (including the severing of all automated ties), rather than an intelligent distribution of computing resources and the sharing of information.

Substantial effort and time has already been devoted to the initial System Decision Paper (SDP) outlining the overall design for an Integrated Management Information System (IMIS) for MSC. Although many key ideas and standards -- such as hierarchical databases, the Open System Interface standard, and local area networks -- have been identified, many of these ideas are still in R&D or at early stages of deployment. Hence, the underlying technologies of IMIS are potentially risky and may lead to delays in implementation. In addition, the past year or more of overall study and design has not provided a detailed analysis of any piece of the system. At the rate at which system needs generally evolve (while the complexity of requirements increases), the system specification may be outdated by the time SDP II is completed, not even considering unforeseen delays.

MSC has employed a top-down design approach to define the functional requirements and overall design guidelines for large, integrated systems such as IMIS. A major bottleneck in this process has been a very limited central staff of (currently three) system analysts. The Command is now moving to implement a strategy of centralized design coordination with: (i) delegation of specific design authority to area commanders and (ii) provision of guidance and guidelines by a central staff. However, a major constraint may still be the limited central resources for coordination and guidance.

By contrast, the systems at MTMC are largely "user-motivated", where the user is defined as a specific functional manager. In addition to requesting system development, the user is responsible for preparing the Mission Element Needs Statement (MENS), the functional description (FD), and the overall data requirements (RD), although the IS staff may be called upon to assist in this process. The success of this approach is at least partially due to the sophistication of MTMC's user community that derives from ten years of experience with computer-based systems. Once the initial functional requirements are determined, the IS staff assumes responsibility for system design and development which may be done either in-house or under contract, depending on resource availability. In general, field level systems are built in the field, while systems for headquarters are developed at headquarters; systems to be shared among several field commands are developed at a designated site, taking into consideration other users' needs, and then propagated to other locations when completed. While MTMC has a staff of over 100 programmer-analysts to draw upon, their effectiveness is multiplied by concentrating their efforts on system design and development since the user does most of the initial requirements and functional analysis.

Concerns in Designing an ADP Systems for MSC

At least four major areas of concern must be addressed in studying the overall design problem for MSC. First, MSC is part of an overall supply and demand process which requires many external interfaces. This interface problem is complicated by the different levels of interaction both in peacetime and war/crisis situations:

1. The Deliberate Planning (strategic/ peacetime) activity involves either actual or potential interfaces with JCS, JOA, MAC, MTMC, CINCS, and the Services.
2. Time Sensitive Execution Planning during a crisis (either an exercise or real world) may require interface with these same agencies, along with MARAD, in order to resolve movement requirements, timetables, and potential constraints.
3. Both Deployment Execution and peacetime operational activities may require the exchange of information with the Services, DLA, DFSC, MTMC, NOSIC, Area Commands, the Coast Guard, MARAD, shipyards, ship operators, and carriers.

As a result, the flow of information is potentially complex, non-standard, and difficult to manage; currently it involves substantial manual intervention and translation or is non-existent.

The internal activities of MSC can also be decomposed by functional area -- such as accounting/finance, engineering, medical, supply, contracting, personnel, and fleet operations. Each area further subdivides into numerous planning, control, and operational activities which may be further complicated by

geographical dispersion; the flow of information among these processes has already been documented as part of the Business Systems Planning study. While external interface standards and contents are either dictated by other agencies or presently undefined, MSC has complete control over the internal interfaces among its own operating units; hence, there is an opportunity to redistribute information among various storage sites while redesigning the flow of information within MSC. In fact, standardization of processing methods and database contents among the different area commands would reduce development and maintenance costs and facilitate the interchange of information for planning and control purposes.

At least some portion of the MSC database is classified information, and in the event of a crisis, additional information -- such as ship location and readiness -- may become so. Any overall system design must facilitate this transition by either providing secure, controlled access during peacetime or permitting the swapping of processing tasks and communication channels to secure sites in the event of a crisis.

As one might expect, the different MSC activities exhibit a wide variation in priorities, response time requirements, volume of information, frequency of occurrence, and locality of data reference. In particular, further localization of data reference can be achieved by wider use of aggregate information in higher level planning and control activities. In any case, an appropriate MIS design must provide sufficient capacity and

flexibility to make appropriate tradeoffs in scheduling the processing load, regardless of the mix of MSC activities or the crisis level.

The general implication of these four issues is that the design of a fully integrated MIS is likely to be a difficult, time-consuming task requiring extensive resources and leading to delays in development if conventional methodologies are employed. Furthermore, the commitment of additional resources beyond the basic design team is as likely to slow down the development process, as accelerate it.

Recommendations

This section provides four general recommendations regarding the design philosophy and methodology used in developing ADP systems for MSC:

1. As mentioned earlier, the designer should use the decision making process as a basis for deriving information needs, rather than simply trying to include information to cover all possible contingencies, in the design of both managerial reports and the supporting database.
2. The design should probably sacrifice generality -- the ability to perform many different tasks or variations -- in order to gain flexibility or extensibility -- the ability to quickly and easily change or augment existing

facilities. A "general" design typically strives to identify and accomodate all of the likely information and processing requirements that exist or may arise in the future. As a result, it usually involves a large expenditure of manpower and a long development period. By concentrating on the underlying decision-making process and selected near and long term requirements, a more modest design can be developed. This design can then be implemented in a modular, extensible fashion using technologies such as database management systems (DRMS) so that the overall system can evolve to accomodate new or changing requirements. Two additional benefits of this approach are that: (i) the system is available more quickly for productive activities and (ii) the effectiveness of the required support can be measured directly through use of the system. Failure to recognize and exploit this tradeoff between generality and flexibility often results in complex designs that are risky and costly to implement.

3. The ADP design should strive for economies of specialization (i.e., avoid the diseconomies associated with providing generalized capabilities) rather than economies of scale. This strategy favors (a) a distributed network of processors over a large, centralized system in order to increase the reliability and reduce the complexity of the system; and

(b) aggregated databases to facilitate higher level planning and control activities rather than global, real-time access to all data, thereby reducing response time and communication requirements and facilitating the exploration of a greater variety of alternatives during the planning process.

4. The design and implementation should employ fourth generation development tools, such as DBMS, nonprocedural languages, and ad hoc inquiry languages, to (a) increase programmer productivity, (b) push more of the development, operational, and maintenance responsibility back onto the end-user; and (c) facilitate the prototyping of early system designs to provide feedback to users, rather than iterating on paper to finalize a design.

5. Assessment of Current Status and Proposed Research

The current systems for supporting defense transportation are flawed in several important ways relative to the ideal perspective described in this report. Most of these shortcomings are generally recognized, but it would be appropriate to briefly list these from our own perspective.

Low Level of ADP Implementation: A critical problem at this time is the low level of ADP systems implementation, especially at the operational level (traffic management) at MSC. A great deal of fairly sophisticated planning has been done at both MSC and

MTMC, but merger issues have delayed both detailed design and implementation. Any progress in improving readiness and responsiveness of defense transportation must recognize the critical need for automating key traffic management functions and their data and organizational interfaces. The first step in improving the situation would be to increase the number of ADP personnel available to MSC for systems analysis and development activities. In parallel, a high-level planning committee should be convened at the earliest juncture to sort out local and global design and implementation responsibilities and to recommend priorities for funding these.

Poor Organizational and System Interfaces: A related problem is the transfer of data and results from existing systems. This relates to both MSC-MTMC tactical responsibilities as well as to the interface of strategic mobilization systems (e.g., JOPS) with mode operators. The present strategy of manual tape transfers and adjustments is both inefficient and potentially disastrous in the event of wartime responsiveness conditions. While many of these inter-organizational "filtering" problems cannot be resolved until an overall system design perspective is adopted, certain key areas can and should be dealt with immediately. The most obvious is strategic mobilization (JOPS and related systems). According to staff in the OJCS, the problem of stating OPLAN requirements to the TOAs is not at a level which can be easily translated to mode-operator planning and feasibility evaluation. Methods for improving the JDA-(MAC-MSC-MTMC) interfaces need to be given high

priority. These would include data compatibility, communications, and systems interfaces, and their potential for automation.

Decision-Oriented Systems Design: A matter of some importance in determining ADP requirements and priorities should be the nature of the decisions supported with ADP. Adopting this perspective, as suggested in the above analysis, would enable a command-oriented design of systems. It would help answer questions like "why is this information needed at this level", "what priority should be attached to the implementation of this system", and "what efficiency and effectiveness criteria should be applied in designing this system for this activity"? Such questions as these are not readily answered for many of the present systems (either in the planning stage or actually implemented).

Local-Global Issues: A final matter of some importance concerning current systems is their lack of focus on the local-global design, development, and implementation issues which figure so centrally in state-of-the-art ADP and decision support systems. The present technology is oriented toward transactions processing with a heavy emphasis on centralized control in all transportation functions which are automated. To be sure, some progress is being made (e.g., in MTMC's local booking-offering-billing systems) towards distributed processing using mini-computers, but there appears to be no joint coherent system design perspective across MSC and MTMC concerning which functions are local (to be dealt with by MSC and MTMC separately)

and which are global--and why? This leads to myopic behavior (e.g., sending rail shipments to ports where no appropriate ship is available) and, worse still, a time-consuming, human-intensive response to enforced global coordination exercises like the generation of OPLANS. A clear philosophy for delineating local-global system definition responsibilities and coordinating the design of global systems is a most important item for the near future.

If the above is a reasonable picture of short-comings in the current system, the following seem to be high pay-off areas for research and development.

System Design: We have spelled out a macro perspective for understanding and improving decision making and planning through decision-oriented systems. Several research and development priorities emerge immediately from this perspective. The most important are implicit in the above comments on the shortcomings of the present system. First, traffic management functions are not likely to change rapidly at the operational level. This suggests an immediate priority of designing operational systems (especially at MSC where the current status is bleak) to realize the benefits which such systems can bring in the short and medium run and to provide a database for building future tactical and strategic systems. Second, the interfaces in strategic mobilization planning between JDA and mode operators should be cleaned up as quickly as possible, with an eye on likely future system developments (e.g., SEASTRAT) within MAC, MSC, and MTMC,

but also in the short-run interest of making strategic mobilization planning more responsive in its current form. Finally, a major study should be undertaken to flesh out a macro design for integrated (but distributed) transportation planning and execution. The ideas of this report may be useful in describing the nature and goals of such a study.

Performance Evaluation: System design efforts are supposed to start with a statement of the objectives of the design effort in question and performance measures for evaluating efficiency and effectiveness of the process one is trying to improve. A major problem with many logistics systems, both private and public sector, is that such performance measures are typically not defined in an operational manner. It is not so much that a general understanding of transportation efficiency and effectiveness is lacking, but rather that no on-going management and command systems are implemented to control it. The typical criteria for evaluating transportation systems are cost, response time (both planning and execution), controllability, and graceful degradation (soft failure). For example, what are the response-time requirements for generating and evaluating OPLANS (to some level of detail) and how well are these met? What are the response-time requirements for resupply of various priorities of equipment and personnel for various source-destination pairs? How are these priorities defined and who sets and controls them? What is response time (an average time, a specified fractile of the response-time distribution, an average across various classes

of cargo, POL, etc.)? As recent work on logistics systems in the private sector has shown, even though such performance measures might be understood in aggregate, translating them into operational terms and designing systems to track them is a complex task, even in the simple case of a manufacturing organization in a peaceful world. Clearly, the environment of defense logistics is much more complicated and deserves a careful study of performance evaluation and management control systems.

Model Development to Support Joint Operations Planning: A final area of importance for future research is model-based support of joint operations planning. As we understand the current planning process, the objective of the exercise is to develop detailed plans down to actual ship schedules (movement tables) that provide the essential operating details for specific scenarios. In a real contingency, however, only a very short time would elapse before the actual situation deviated significantly from the anticipated scenario, and thus such detailed plans would be useless. That is, the current approach develops plans to satisfy highly uncertain demands as though there were no uncertainty, and does this planning in great detail. This concept does not make a great deal of sense, and therefore research based on other concepts of planning would be very worthwhile. The principal virtue of the current planning mode is that it provides a starting point for the mobilization process. In addition, the existence of a feasible plan assures that the system can respond at least in some situations if, in fact, a feasible plan can be worked out.

What is needed is a planning approach that recognizes that the specific scenarios used in mobilization planning will never materialize in practice simply because the detailed requirements of a real contingency are unpredictable. An analogous situation arises in manufacturing enterprises, and therefore, planning and control methods from the industrial sector could serve as a basis for a better approach to mobilization planning in the military.

The analogous situation in a manufacturing setting is called an "open job shop". A job shop is a set of facilities, typically groups (machine centers) of equipment. The demands placed on the facilities are "jobs" or "orders", each of which has a particular required, possibly unique, routing through various machine centers. Moreover, the time required to process a job in a machine center varies from job to job. The "open" descriptor refers to the fact that the enterprise accepts orders originating from outside the firm, and thus, the firm does not have total control of the demands placed upon it. To draw an analogy with military logistics, the demands for movement of cargo, people, and POL are the jobs, while the rail resources, port facilities, and ships of various kinds are the machine centers.

The goals of successful management in a job shop are not too different from those in a transportation system: the firm is concerned with maximizing throughput, meeting delivery dates, minimizing work in process inventory (jobs in the system), and

efficiently utilizing resources (to minimize the cost of alternatives such as overtime, subcontracting, or turning away business).

A job shop requires a vast number of decisions to keep it in operation, varying in importance from what products should be manufactured, what facilities should be operated, and how many workers of various skills are required each month, to what should be the routing of a particular order and what job should be done next in the milling machine department. Two characteristics of planning in this environment are that (1) the set of decisions and data requirements are much too extensive and complicated to make all decisions simultaneously and (2) it is impossible to schedule the detailed movements of individual jobs very far in advance of the time when the movements are to be carried out simply because there is no way to predict exactly what jobs will be in the shop. Moreover, there are many random perturbations due to machine breakdown, quality problems, material shortages, rush orders, and the like.

How do companies cope with all of this? The most successful firms adopt a hierarchical approach whereby they make the significant long term decisions with aggregate data. As they move down the hierarchy of decisions, the decisions become more detailed and cover shorter time spans. As explained in Buffa and Miller [1979] or Holstein [1968], a typical four-level hierarchy of decision making would be:

- (1) Long term capacity planning: major adjustments of capacity to match projected requirements.
- (2) Master scheduling: match available capacity to individual products (typically, projected monthly demands over 6 to 18 months) and major orders. Minor capacity adjustments such as those involving overtime and subcontracting.
- (3) Short-term scheduling: more detailed and shorter time horizon than master scheduling in order to ensure that delivery commitments can be met.
- (4) Dispatching and shop control: immediate (virtually real-time) decisions to assign specific tasks to individual machines and workers.

In the analogy with mobilization planning, it seems that the current method is to try to do steps 2, 3, and 4 all at once, even though the dispatching decisions must be made all over again when the time comes to put the plan into action. It seems clear that a better job of planning can be done through the use of an analogous hierarchical planning system similar to that employed in large industrial job shops.

The key to devising a good hierarchical planning system is to develop ways of forecasting demands with the proper degree of aggregation at each level of the hierarchy and to employ decision

aiding models appropriate for each level. A model is used not only for specific decisions, but also as a means of testing higher level decisions and setting the conditions and constraints for lower level decisions. Moreover, a model is used for a number of activities: answering what if questions, testing boundary conditions, diagnosing problems, and experimenting with alternative solutions. These capabilities are more important than the ability to work out in detail a single, specific scenario with (inappropriately) presumed certainty.

In the job shop scheduling world, effective ways have been developed for dealing with step 3 of this process -- i.e., short term scheduling. The general method incorporates the rules and procedures used in dispatching and control (step 4) into a flow model that simulates the movements of jobs through the shop.

We believe that the philosophy of hierarchical planning and control we have outlined here holds promise for mobilization planning. The research that we propose would begin by defining the planning and control levels appropriate to joint operations planning. Questions to be answered include: what levels of data aggregation and kinds of supporting models are needed, and how do planning models at the various levels interact? Given those results, we would want to understand how the actual process would change if supported by such models. What would be the benefits in terms of information that would be available to decision makers, and how robust and effective would the resulting plans be?

This hierarchical approach is also consistent with the recommendations made earlier concerning system design. By breaking the planning process into modular pieces, it will be possible to change isolated portions while leaving the others intact, as better approaches to each aspect of the problem are developed. This will encourage evolutionary growth and is much better than trying to design a monolithic system from the start, especially when the design may be based on a poor concept of how to solve the overall planning problem.

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